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EMAIL AND ATTACHED REVISED TECHICAL MEMORANDUM AQUIFER FLUSHING AND GROUND WATER SAMPLING ISSUES NEW WELLS AT SITE 16 NCBC DAVISVILLE RI
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Subject: Revision of EPA's TM on Davisville, NCBC, OU9-well development issues
Attachments: MW16-82D-Fig-2.xls; MW16-84D_Fig-1.xls; wells.pdf; Revised Aquifer Flushing and Groundwater Sampling Technical Memorandum.doc; Revised TM-Tables.doc

Hard copy to follow.

(See attached file: MW16-82D-Fig-2.xls)(See attached file: MW16-84D_Fig-1.xls)(See attached file: wells.pdf)(See attached file: Revised Aquifer Flushing and Groundwater Sampling Technical Memorandum.doc)(See attached file: Revised TM-Tables.doc)

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Technical Memorandum

NCBC Site 16
Aquifer Flushing and Ground Water Sampling Issues – New Wells

Introduction

During Fall 2008, EPA performed a comprehensive review of the Phase III RI for Site 16. A number of issues were consistently identified that reflected mainly on the new wells installed during the most recent (2008) field effort. In an effort to understand this information, records regarding well installation, development, slug testing, and sampling were reviewed systematically and in detail. The central goals underlying the review conducted and recommendations outlined in this technical memorandum (TM) were to verify whether the ground water samples collected and reported in the Phase III RI were representative of ground water quality conditions in the aquifer, and whether reported hydraulic conductivity values were reflective of the geologic materials reported at the wells. In order to be representative of in situ ground water quality, the sample collected must be free of any non-representative influences or interferences that may affect the analytical results. These influences can include dilution due to lost drilling water that is not recovered; stagnation of well water due to hydraulic isolation of the screened interval from the aquifer resulting from smearing of the outer borehole during drilling; non-representative sample collection due to short-circuiting from ground water flow along the bore hole/annulus as a result of inadequate grout/seal; excessive aeration of the ground water prior to sample collection that could result in air stripping of volatile organic compounds (VOC); etc. Review of the data indicates that one or more of these concerns are indicated for many of the recently monitoring wells installed at Site 16. For many of the wells, several problems have been identified. A detailed discussion of the specific issues identified at specific wells follows, below. Borehole "skin effect" and leaky borehole seals have been identified in several wells. In order to arrive at representative ground water quality and hydraulic conductivity values, a number of recommendations have been offered as a way forward. Re-development of problem wells listed below is the necessary first step. Following redevelopment, it will then be possible to re-slug and/or resample specific wells as needed. In some cases, a change in sampling method, e.g., to passive diffusion samplers, is suggested as a way forward in the face of a leaky well seal. While these suggestions may not in all cases represent an optimal solution, EPA shares the Navy's goals of completing the Phase III RI for Site 16, with the support of technically defensible data. It must therefore be acknowledged that, if the recommendations offered below are not successful in mitigating the problems identified, it may be necessary in selected cases, to reinstall carefully constructed new wells.

Deep Overburden/Shallow Bedrock Hydraulic Conductivity Values

The hydraulic conductivity values provided in the Phase III RI provided one line of evidence that potential problems existed with the data. The previously submitted aquifer flushing time estimates prepared by GF-CDW incorporated hydraulic conductivity data provided by the Navy that was derived from slug tests conducted on the monitoring wells. The resulting aquifer flushing times were interpreted to be excessively long by the Navy. As a result, it was requested that alternative aquifer flushing times be calculated using values for hydraulic conductivity of the deep overburden and shallow bedrock that were interpreted to be present at the site by GF-CDW. The hydraulic conductivity values that were determined by GF-CDW to be present in the deep overburden were based on what are deemed to be likely minimum hydraulic conductivity values as determined by the United States Geological Survey (USGS). The following table presents expected ranges of horizontal hydraulic conductivity for aquifer materials provided in Table 1 of the United States Geological Survey (USGS) Open File Report 02-197, "*Documentation of Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data*". The values listed above are in ***feet per day***.

Table 1: Ranges of Hydraulic Conductivity Values for Aquifer Materials (USGS).

Aquifer Material	***Likely Minimum***	Likely Maximum
Gravel	**300**	3,000
Sand & Gravel Mixes	**30**	300
Coarse Sand	**70**	300
Medium Sand	**20**	70
Fine Sand	**3**	20
Fine Sand & Silt Mix	**0.1**	30

Data is not provided for highly weathered and/or fractured meta-sedimentary rock such as phyllite which appears to be present throughout the Site 16 area. However, from Table 1.7.2 of "*Analysis and Evaluation of Pumping Test Data*" 2nd edition, Kruseman and de Ritter, ILRI Publication 47, 1994, fractured or weathered rock may have hydraulic conductivity values ranging from near 0 to as high as 984 feet per day.

The following table lists the recently installed monitoring wells with the associated aquifer material in which the screen is positioned as determined from the descriptions provided in the soil boring and rock coring logs. Also shown are the applicable USGS "Likely Minimum" or estimated bedrock hydraulic conductivity values, and Phase III Remedial Investigation slug test derived hydraulic conductivity values for those wells.

Table 2: Comparison of USGS, Reference, and Slug Test Conductivity Values[1]

	Aquifer Material Description	**USGS Hydraulic Conductivity or Estimated Rock K**	**Navy Slug Test K (Rising Head)**
MW16-10I	Very fine to fine sand.	(Fine Sand) > 3 feet per day.	3.74 feet per day
MW16-13R	Lower 10 feet had average RQD = 37% and 42 fractures.	Estimated at > **30 feet/day.**	2.04 feet per day
MW16-82D	Predominantly angular rock fragments	(Sand/Gravel mix)	0.58 feet per

	with silt and sand.	**>30 feet per day.**	day
MW16-82R	Upper 10 feet had average RQD = 39% and greater than 40 fractures.	Estimated at **> 30 feet/day.**	0.78 feet per day
MW16-83D	Fine to medium sand with much gravel and fractured rock, some silt. Notes: "filed tub with gravel, lost 150 gallons, and lost 200-300 gallons".	(Sand/Gravel mix) **>30 feet per day.**	0.63 feet per day
MW16-83R	Appears to be in weathered rock. No core, well in roller bit zone. Notes: "much/lots flat, angular rock frags", and "very weathered".	Estimated at **> 30 feet per day.**	0.64 foot per day
MW16-84D	Sand, silt, gravel and rock. Notes: "taking water" & "sucking even more water".	(Sand/Gravel mix) **>30 feet per day.**	4.43 feet per day
MW16-84R	Average RQD = 85% and few fractures.	Estimated at **1 to 10 feet per day.**	7.66 feet per day
MW16-86D	Silty, fine to coarse sand and gravel throughout.	(Sand/Gravel mix) **>30 feet per day.**	1.6 feet per day
MW16-86R	RQD = 0% for the five foot screen section. "Highly fractured". Notes: "May need to insert casing to prevent collapse of highly fractured section".	Estimated at **> 30 feet per day.**	12.46 feet per day

1. Slug test hydraulic conductivity values excerpted from Phase III RI for Site 16

The table shows that there is reason to suspect that the slug test hydraulic conductivity results obtained during the Site 16 Phase III Remedial Investigation underestimates the in-situ hydraulic conductivity for the all of the deep overburden wells and four of the shallow bedrock wells listed in the table. For the most part, the difference in the expected minimum hydraulic conductivity value and the Phase III Supplemental Remedial Investigation slug tests values vary by one to two orders of magnitude. It should be emphasized that in making this comparison the USGS "Likely Minimum" value for "Sand and Gravel Mixes" was used. The actual hydraulic conductivity may be higher.

Bore Hole Skin Effect:

The discrepancy between the USGS expected minimum value for hydraulic conductivity and the slug test derived value is likely the result of reduction in permeability in the outer borehole wall resulting from the effects of well drilling and inadequate well development following well construction. According to "The Design, Performance, and Analysis of Slug Tests", J.J. Butler; page 12: "well development is the single most important aspect of a program of slug tests". During the installation of the well the borehole wall can become smeared with fine grain material either due to simple smearing effects as the casing (or auger) pushes and presses against the formation such that the soil matrix is compacted/filled with finer grain soils. This effect is often exacerbated through transport of finer grain material from higher elevations. The result of this smearing is that it creates a borehole "skin" that results in an observed reduction of the aquifer hydraulic conductivity during the slug test if the well is not adequately developed ("Applied Hydrogeology", C.W. Fetter, 4th edition, page 204-205; "Groundwater Hydrology", D.K. Todd & L.W. Mays, 3rd edition, page 273; and "The Design, Performance, and Analysis of Slug Tests", J.J. Butler, page 171).

The "skin effect" can also be created and/or worsened by the introduction of cement and clay such as when cement-bentonite grout or bentonite pellets/chips are inadvertently introduced into the aquifer adjacent to the screened interval. Review of the well construction logs notes that at most, there is a two foot filter sand separation between the top of the well screen and the bentonite seal. For two wells (MW-16-13R and MW-82R) there is only a 1.5 foot separation and for MW16-86R there is only a 1.0 foot separation. This small separation may have been insufficient to prevent migration of bentonite into the well screen (particularly if other aspects of the well installation procedures were sub-optimal). Guidance provided United Facilities Guide Specifications (UFGS) recommends a minimum three foot separation.

Review of the well construction logs also shows that the well annulus is only 0.81 inches from the outer well casing for the overburden wells and only 0.75 inches for the bedrock wells. This is based on the borehole diameter of 4 inches for the overburden wells and 3-7/8 inches for the rock core hole combined with an outside diameter of 2-3/8 inches for the two inch monitoring well screen. The UFGS notes the importance of precise placement of the filter pack such that there are no void spaces. For instance, the filter pack should be placed using a tremie pipe and not be poured directly from the ground surface. Also, the well should be plumb during placement of the filter. If these actions are not carefully implemented voids can be created; migration of bentonite to the well screen interval may be a consequence. While it is accepted that every effort was likely taken to ensure tight borehole annulus seals, the narrowness of the well/borehole annulus and depth of the wells provided significant obstacles to achievement of this goal. Given the extremely narrow annulus around the wells, accurate emplacement of an effective filter would have been very difficult.

Additional evidence suggests that transfer of bentonite into the screened interval appears to have occurred in most of the recently installed wells as indicated by; 1) the elevated well water pH and; 2) the extremely high turbidity levels. If the well is not adequately developed to remove any fine grain material and the lost bentonite, thereby eliminating the "skin" around the borehole, a lower than actual hydraulic conductivity will result from slug testing. This effect of introduction of bentonite into the screened interval is not dissimilar to the introduction of bentonite drilling fluids that are used to keep holes open during water well drilling ("Design and Construction of Water Wells", J. Lehr, et. al. page 38-45). In this procedure, the bentonite produces a filter cake which has to subsequently be removed prior to operation of the well. It must be noted, however, that a compromised well seal may not – in all cases – be remedied by additional well development. In severe cases, a new (replacement) well may need to be installed. However, as a next step, a more aggressive re-development effort is warranted to determine whether the wells in question may be salvaged.

Ground Water Quality

An assessment of ground water quality provides additional support to the interpretation of significant smearing of the borehole annulus around the screened interval of the monitoring well as described above. Information relevant to the specific wells evaluated is provided in Table 3. The table documents elevated turbidity and pH that is often associated with the presence or residual bentonite and/or bentonite-cement grout that has been introduced into the screened interval and not removed from the well annulus. For a well to be considered developed the pH should be near that of ambient ground water (around 6.0 to 6.5 for the Site 16 location). The turbidity should normally be less than 5 Nephelometric Turbidity Units - NTU (EPA Technical Enforcement Guidance Document - 530/R-93/001).

Inspection of the data on Table 3 shows that many of the wells have not been adequately developed in order to reestablish a hydraulic connection between the well screen and the adjacent aquifer. This is a major concern. For MW16-82D/R especially, the turbidity remained extremely high. While the turbidity was lower for other wells, it remained above what would normally be expected for an adequately developed well (i.e., < 5 NTUs). In all wells the pH remained elevated above ambient background. In other wells such as MW16-84D/R and MW16-86D/R the pH increased substantially during sampling indicating passage of ground water from shallower elevations through the borehole annulus with ground water that had been in contact with the well seal materials.

<u>MW16-86D/R:</u> This well pair merits special comment. Similarly to MW16-84D/R there was a dramatic increase in three pH units from time of development to time of sample collection which occurred in 1 and 4 days, respectively, for MW16-86D and MW16-86R. However, in addition to this dramatic increase in pH, there was also an accompanying decline in ground water temperatures. The ground water in MW16-86D dropped approximately almost 3° C while the ground water in MW16-86R dropped over 4° C. Since these wells were developed and sampled in December it is likely that this marked drop in ground water temperature results from inflow of colder shallower ground water from the upper portion of the saturated zone.

What potentially sets this well pair apart from other wells such as MW16-84D/R where there was a marked increase in pH between the time of well development and sampling is that there appears to have been a significant volume of ground water extracted at MW16-86R when the well was developed on December 13, 2007. Extraction of this volume of water likely accounts for the drop in ground water temperature between the date of well development and sampling. During the extended pumping, shallower ground water was likely induced to migrate to deeper elevations whereby when subsequently sampled resulted in the colder ground water temperatures being recorded The increase in pH and the drop in temperature suggests migration of ground water along the borehole past or through a leaky borehole grout/seal rather than from the adjacent aquifer materials. Further comment on the leaky borehole grout/seal is provided below.

While the Navy has indicated that the recorded water extracted at MW16-86R was a "glitch" the well development log for MW16-86R nonetheless, clearly documents that 1,510 gallons (5,715 liters) of water was extracted from that well during an eight hour period from 08:30 to 16:40 on that day. The purge time is listed as 490 minutes (8 hours and 10 minutes); and water quality data and ground water elevations were recorded. It is also noted on the log that the pump was a submersible pump not a low flow pump. Since this document has been included in the Phase III Supplemental Remedial Investigation Report, it is assumed that it had been checked for quality control and is therefore, reflects actually implemented activities.

MW-Z4-02D:

While not originally intended to be part of this review, a comment on the well development and sampling results for MW-Z4-02D, which lies up gradient along Thompson Road is warranted in respect to other potential leaky seals and the potential for having sampled ground water at elevations higher in the saturated zone than the intended screened interval. The well development log shows that 66 gallons of water was removed from this well with a submersible pump on December 11, 2007. No dissolved oxygen was recorded, but the pH was 7.45 units and the turbidity level was 85 NTU.

The well was subsequently sampled 6 days later with an additional 6 plus gallons of water being removed. The initial dissolved oxygen measured was 4.9 mg/l suggesting that the well had been aerated during development. The pH jumped to 10.5 units and the temperature was approximately 11° C even though deep ground water temperature for nearby MW16-83D/R was around 14° C. These results suggest that ground water sampled from MW-Z4-02D was derived from a zone above the screened interval, having migrated through a leaky borehole seal. Low level of chloromethane was detected in this well which may have been a diluted value of actual in situ concentrations.

Review of Slug Test Data

As part of this review, the slug test raw data for the recently installed monitoring wells was also checked to assess the observed discrepancies between the expected hydraulic conductivity values based on the aquifer material descriptions and those derived from the slug tests. It was noted that for many, if not all, of the slug tests the early time data was not considered in the calculation of the hydraulic conductivity or in assessment of the integrity of the well seal.

Recent Navy comments stated that early time data can be dismissed when evaluating the slug test responses. This is not correct in all cases. If there are two slopes in the recovery data, and the first comprises a relatively modest portion of the recovery, and the well has been well developed with little or no bore hole smearing remaining, the early time data may (should) be ignored and the second recovery slope be used to assess aquifer hydraulic conductivity. It should be emphasized, however, that this two slope pattern still signifies a major problem; that being leakage around the well casing through the well annulus grout/bentonite seal. Therefore, the early time data cannot simply be dismissed.

Evaluation of the slug test data is not complete without evaluating the entire slug test recovery response as well as performing a comparative check of the results with the aquifer material descriptions as noted previously.

For example, this limitation is illustrated when reviewing the slug test recovery response for MW16-84D and the soil boring log description for that well where the slug test calculated hydraulic conductivity and aquifer material description suggests that the slug test and expected hydraulic conductivity are off by an order of magnitude. Figure 1 shows a two slope response for MW16-84D. While the first slope is interrupted by an oscillation there are clearly two slopes in the recovery data. The first, steeper slope, lasting 2 seconds, beginning at the 4 second mark, indicates leakage from the borehole annulus that contributes to the early recovery prior to the break in slope at around the 6 second mark. Therefore, while the second slope is shallower resulting in a lower than expected hydraulic conductivity for that well, given the aquifer materials described for the screened interval, there is also an additional impact from a leaky well/borehole annulus seal. Evaluation of the early time data for other wells also points to inadequate well seals with similar two slope recovery responses.

Additionally, many of the slug tests recovery responses show significant oscillations lasting several seconds prior to onset of the following relatively stable recovery slope. The plot of the early time data for the rising head slug test for MW16-82D as an example is attached as Figure 2. It can be seen that there are high amplitude swings in the initial response followed by a negligible recovery response. While some slight oscillation might be expected after removal of the slug, the magnitude of the response is not. The amplitude of the swings is over 4 feet lasting for several cycles over several seconds. The response following slug removal suggests a special condition.

The wide oscillations can occur where the aquifer adjacent to the screen is sealed (i.e. has a "skin effect") or is otherwise of very low permeability, thereby creating a "double casing", combined with a permeable annulus such as would occur with lack of a viable seal above the well screen. The observed wide oscillations likely occur due to "inertia induced" fluctuations of the water level in the annular space between the inner and outer casing. This condition is described in "Analysis of Slug-Test with High Frequency Oscillations", by O. Audouin, and J. Bodin, Journal of Hydrology, 334 (2007), pages 282-289. Analysis of the oscillations for MW16-82D indicates that the response is not due to effects of the water column within the well, but rather due to fluctuations in the annulus outside of the well. Where there is not a tight seal restricting flow, the water is exchanged with the more permeable annulus material thereby moving downward into the screen and then upward and back again until the energy is dissipated.

Again, as with the two recovery slopes, the early time data cannot be summarily discounted. While it is valid to say that this early time data does not reflect the hydraulic conductivity of the aquifer and can be ignored for that purpose, it is providing significant information relative to the lack of an effective well annulus borehole seal. Therefore, combined with the apparent two recovery slopes for most of the slug tests in the recently installed monitoring wells, the oscillations in the early time data strongly suggest that there is an inadequate borehole seal to prevent short-circuiting of shallower ground water from higher in the saturated zone from migrating downward into the screened interval of the deep overburden and shallow bedrock wells.

Leaky Borehole Annulus Seal:

As noted above, inspection of the slug test recovery data for most of the monitoring wells indicates that there are two different slopes as well as unexplained wide oscillations in the recovery data for the rising head tests. This suggests that in addition to a borehole "skin effect" there is also a leaky borehole annulus seal for most of the recently installed monitoring wells. The leaky borehole annulus seal provides an additional concern for collection of samples using pumping methods since ground water collected is likely to be influenced by migration from higher intervals in the saturated zone outside the targeted portion of the aquifer adjacent to the screened interval.

Excessive rapid loss or gain of pressure head should not be observed with a well that has a tight seal, in that water will be directed into or out of the aquifer material immediately adjacent to the well screen. If a poor seal is present, ground water will recharge the well from the packing material surrounding the riser ("Groundwater Hydrology", D.K. Todd & L.W. Mays, 3rd edition, page 263-264"; "Applied Hydrogeology", C.W. Fetter, 4th edition, page 199-200). Also, for several of the slug tests, there is a large degree of oscillation of water levels during the first few seconds that accompany the steep slope. This also suggests a poor or non-existent well seal where water is free to move within this more permeable material as opposed to being restricted to horizontal flow into and out of the well screened interval.

Figures 3 and 4 shows what occurs to account for the first slope and the observed wide oscillations. Figure 3 (middle) shows a monitoring well with a tight annulus seal and a leaky seal without oscillations. For a well with a tight seal, when water is withdrawn from the well there is a decline within the well casing only followed by a rise in water level within the casing back to the starting level. Ground water flows into the well from the aquifer only. When there is a leaky borehole seal (fig 3 right) as water is withdrawn from the well there is a decline within the well followed by water flowing into the well first from the relatively permeable well annulus causing a sudden rise within the well and a decline in the water level in the borehole annulus until the water levels within the well and in the annulus reach equilibrium. This accounts for the first slope observed in the early time data. The second, shallower slope will result as water subsequently rises to the initial elevation as ground then enters the well from the aquifer. Under conditions of significant "skin effect" all of the remaining recovery may result from slow drainage into the annulus with an equivalent rise in the well.

Figure 4 shows what occurs when the annulus outside of the well is filled with water as occurs when there is a double casing, or has a highly permeable annulus that can occur with sloughing of borehole wall material, bridging caused by ineffective placement of bentonite chips or pellets, filter sand, and/or secondary channels in the grout. Upon removal of water in the well, there is a surge of water into the well from the annulus pushing the water in the well higher than the initial elevation followed by a return push back into the annulus. This cycle continues until the energy is dissipated. The number of cycles, magnitude and duration, etc. will be affected by the actual degree of permeability and channeling within the annulus.

Conclusions

Aquifer Flushing

A recalculation of likely ground water flushing times was performed for each of the newly installed wells using an assumed USGS "Likely Minimum" hydraulic conductivity value for "Sand and Gravel Mix", 30 feet per day. Using this hydraulic conductivity value, a hydraulic gradient of 0.002 feet per foot, and an effective porosity of 0.25, the ground water seepage velocity will be approximately 0.24 feet per day or approximately 87.6 feet per year. If this revised ground water velocity is used it will allow flushing of a volume equal to three times the maximum volume of lost drilling water for any well such that given the elapsed time since the wells were last sampled (December 2007) the aquifer surrounding the monitoring wells (but not necessarily within the wells) will have at the present time been flushed clean of any drilling water that was lost. However, additional technical issues remain, as discussed below; additional actions are needed.

Monitoring Well Limitations

Analysis of the data indicates that two significant issues remain that preclude allowing sampling at this time. These will need to be resolved prior to additional sampling.

Borehole "Skin Effect"

As discussed above, there appears to be a borehole "skin effect" for virtually all recently installed wells and leaky well annulus seals for nearly all of those same wells. This is indicated by the following:

- Slug test recovery times that do not correlate with aquifer material descriptions.
- Extremely elevated pH indicating the presence of cement and/or bentonite.
- Elevated turbidity levels indicating excessive presence of fine grain material.

Wells with a smeared zone around the well screen annulus are not likely to yield a ground water sample representative of the aquifer. Water within these wells is likely stagnant and is poorly connected or effectively disconnected from the adjacent aquifer water. Wells with excessive borehole "skin effect" will need to be re-developed to re-establish a hydraulic connection with the aquifer and ensure that all stagnant residual water in the well casing is removed. Without re-development, these wells cannot provide reliably representative data.

Leaky Borehole Seals

Additionally, all recently installed wells appear to be affected by borehole seals that have significant leakage. This is indicated by the following.

- An apparent two slope response during recovery.
- Severe oscillations during early time during recovery.
- Increases in pH during sampling indicating downward flow along the borehole.
- Unexpected temperature changes during development (e.g., shallow water pulled to deeper levels
- Unexpected temperature changes during development (e.g., shallow water pulled to deeper levels

Because of the significantly leaky borehole seals surrounding these wells, future sampling using pumping methods is not recommended. Because of the leaky seals, pumping is likely to draw in ground water from higher elevations in the saturated zone from above the screened interval. That is, even with restoration of connection with the aquifer, there will be preferential flow along the borehole under pumping conditions. As such, the reliability of the sample to represent in situ ground water quality adjacent to the well screen interval is highly questionable.

Recommendations

Recommendations for wells that will need to be re-developed or replaced are provided on Table 4. All but two of the wells will need to be re-developed prior to sampling, and ideally even those should be re-developed. Following redevelopment, redeveloped wells should re-slug tested. The slug test results should be compared to pre-development slug test data and physical aquifer material descriptions (soil and rock) in order to determine whether an improved hydraulic connection to the aquifer has been achieved, and whether hydraulic conductivity values are realistic. At this point collection of additional ground water quality samples may be considered. Prior to ground water sampling, a sampling break of 14 days needs to occur after completion of well re-development prior to re-sampling the wells.

Because of leaky borehole seals for all wells, future sampling using passive diffusion bag samplers placed at 5 foot intervals within the screen is recommended in lieu of low flow sampling. If passive diffusion sampling is not selected, sampling with any method that will draw in ground water from locations other than directly opposite the well screen must be avoided.

Additional Wells Recommended for Re-Sampling

The following wells should also be re-sampled or in the case of TW-105D (MW-75D) for the first time if possible or replaced. These were "Priority 2" wells, but should be included. These wells do not need to be re-developed except for MW-75D which was not previously sampled. However, they should be sampled with a passive diffusion bag similar to the other Site 16 wells.

Well	Develop	Sample	Comment
MW16-55D	No	Yes	This well had a pH of 8, dissolved oxygen = 3.0 mg/l, and turbidity in excess of 1100+ NTU when sampled in 2004. The well construction log shows only 1 foot of filter sand above the top of the well screen. There appears to be a leaky borehole seal.
MW-73D (TW-103D)	No	Yes	The well had a pH = 8.0 during sampling. The construction logs show that the DPT wells have a borehole annulus of only approximately 0.5 inches. There is a likely a leaky seal. Also, the well was sampled only 1 day after development.
MW-74D (TW-104D)	No	Yes	This well was sampled on the same day that it was developed. Low concentrations of TCE were nonetheless detected in this well.
MW-75D (TW-105D)	Yes	Yes	This well was never sampled. It lies in the vicinity of MW-Z4-02D which had low concentrations of chloromethane detected.
MW16-55I	No	Yes	Well developed and sampled the same day.

Figure 1: MW16-84D Rising Head

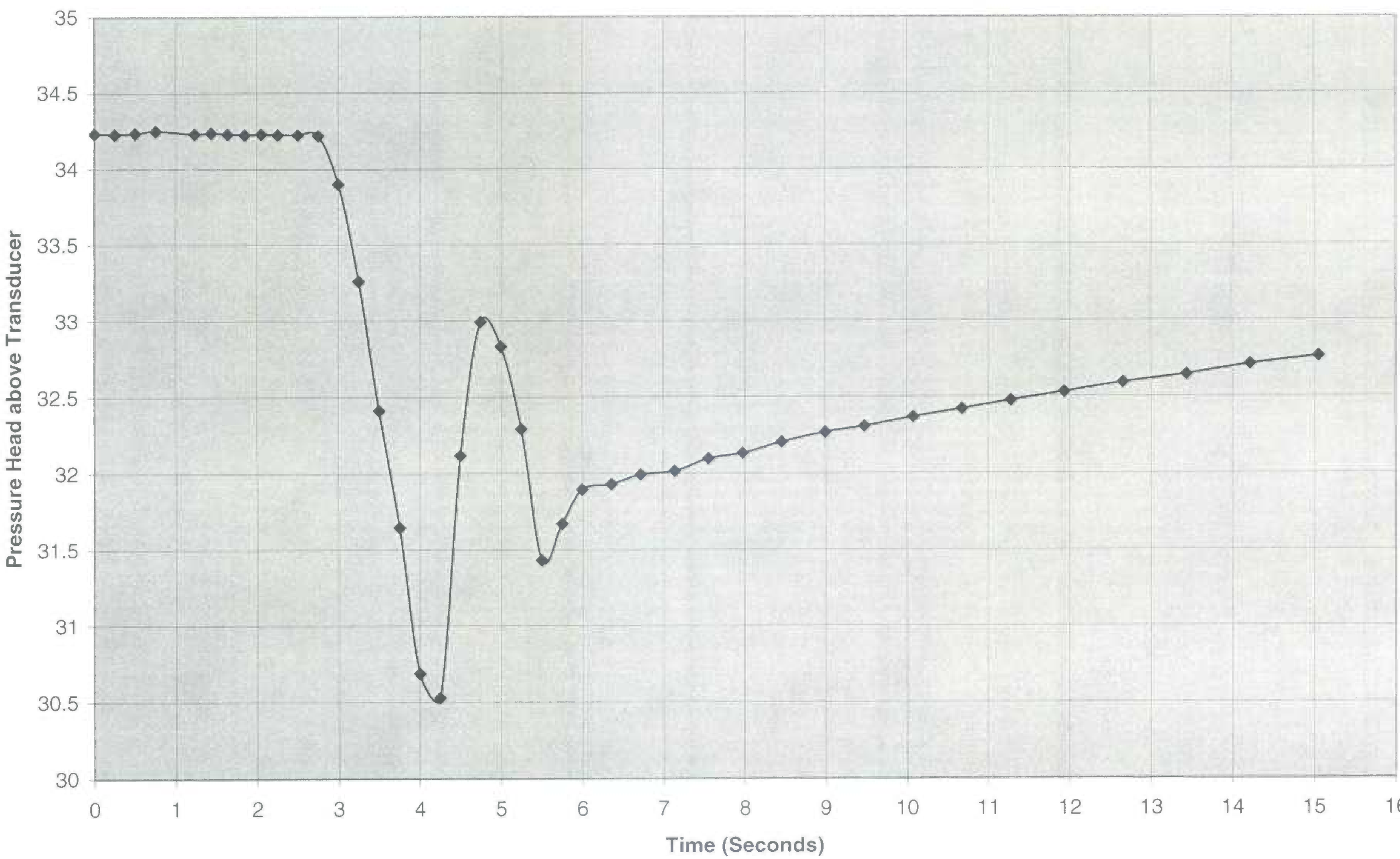

Table 3: Ambient Ground Water Quality Indicators

	During Development				During Sampling				
Well	**pH**	**T°C***	**DO***	**NTU**	**pH**	**T °C***	**DO***	**NTU**	**Comment**
MW16-13R	8.63	15.2	4.22	130	8.97	14.5	0.36	184	Well developed by surging and pumping only 4 days prior to sample collection. Extremely high pH and elevated turbidity during sample collection.
MW16-10I	9.45	17.1	6.36	10	9.98	16.4	0.55	26	Well developed by surging and purging with bailer only 3 days prior to sample collection. Extremely high pH during development remained at time of sampling.
MW16-82D	8.06	15.2	4.50	1100+	7.74	15.4	0.27	1100+	Well developed by surging with bailer 2 days prior to start of sampling. Extremely high turbidity and elevated pH remains at time of sampling.
MW16-82R	8.20	17.0	1.02	700	8.33	16.2	0.43	1100+	Well developed by surging and purging with a bailer prior to start of pumping. 6.45' of sediment removed from well. Extremely high turbidity and elevated pH at time of sampling.
MW16-83D	7.06	14.7 Dec.	N/A	0	7.10	14.2 Dec.	2.86	48	Dissolved oxygen not recorded during development. High DO present during sampling (started at 6.08 dropping to 2.68 mg/l) 7 days after development. Turbidity jumped to >999 during sample purging prior to settling back to 48 NTU.
MW16-83R	7.89	13.0 Dec.	6.51	215	8.14	13.4 Dec.	3.07	35	High dissolved oxygen remained in well at time of sample collection 6 days after well development. Elevated pH also in well at time of sampling, increasing from during development time.

Note (*): Dissolved oxygen for development was the high recorded indicating level of oxygenation during development.
Ground water developed/sampled in October except where noted (Dec. = December).

Table 3: Ambient Ground Water Quality Indicators (Continued).

	During Development				During Sampling				
Well	**pH**	**T°C***	**DO***	**NTU**	**pH**	**T°C***	**DO***	**NTU**	**Comment**
MW16-84D	6.59	18.5	4.98	170	8.93	12.7 Dec.	2.55	250	The pH of ground water increased significantly from development to time of sampling to an extremely high level. Likely bad seal. Elevated dissolved oxygen remained in well at time of sampling. Turbidity also remained elevated.
MW16-84R	6.62	14.8	3.44	16	9.98	13.6 Dec.	2.51	21	The pH of ground water increased significantly from development to time of sample collection. Likely bad seal. Elevated dissolved oxygen was also present at time of sampling.
MW16-86D	6.92	12.6 Dec.	8.08	0	9.48	10.0 Dec.	1.51	96	Well sampled 1 day after development. Unexplained significant increase in pH to extremely high level. Also, there was also a drop in ground water temperature of almost 3° C from 12.60° C to 10.04° C between development and the one day elapsed to sampling. Combined with the increase in pH this may indicate inflow of colder shallower ground water since this well was developed and sampled during December.
MW16-86R	6.90	12.6 Dec.	7.58	0	10.36	8.2 Dec.	2.15	40	Well sampled 4 days after development. Unexplained significant increase in pH to extremely high level as well as elevated concentration of dissolved oxygen at time of sampling. Similar to MW16-86D there is an unexplained anomaly with a substantial drop in ground water temperature of over 4° C from 12.62° C to 8.05° C. Combined with the increase in pH this may indicate inflow of colder shallower ground water since this well was developed and sampled in December.

Note (*): Dissolved oxygen for development was the high recorded indicating level of oxygenation during development.
Ground water developed/sampled in October except where noted (Dec. = December).

Table 4: Monitoring Well Limitations Summary and Recommendations for Actions Prior to Re-sampling.

Well	Skin Effect	Leaky Seal	Re-Develop	Comments
MW16-10I	?	Yes	"No"	The response for this well is marginally acceptable. The "skin effect" is present, but to a lesser degree than other wells. Slug-test derived K values within expected range. Ideally, it should be re-developed.
MW16-13R	Yes	Yes	Yes	Only 1.5 feet of filter between seal and screen. Only 0.75" clearance: screen O.D. and rock wall.
MW16-82D	Yes	Yes	Yes	Due to excessive turbidity and pH it is likely that this well will need to be replaced.
MW16-82R	Yes	Yes	Yes	Only 1.5 feet of filter between seal and screen. Only 0.75" clearance: screen O.D. and rock wall. Similarly to MW16-82D this well will likely need to be replaced.
MW16-83D	Yes	Yes	Yes	Poor response during slug test response (i.e., well skin effect)
MW16-83R	Yes	Yes	Yes	Only 0.75" clearance: screen O.D. and rock wall.
MW16-84D	?	Yes	Yes	The response for this well is marginally acceptable. The "skin effect" is present, but to a lesser degree than other wells. Ideally, it should be re-developed.
MW16-84R	?	Yes	"No"	Only 0.75" clearance: screen O.D. and rock wall. It is difficult to determine whether the slow response is due to few fractures or "skin effect". Slug-test derived K values within expected range. Ideally, it should be re-developed.
MW16-86D	?	Yes	Yes	While this well has a response that will allow sampling using diffusion bag samplers the calculated hydraulic conductivity appears to be underestimated. Ideally, it should be re-developed.
MW16-86R	Yes	Yes	Yes	Only 1.0 feet of filter between seal and screen. Only 0.75" clearance: screen O.D. and rock wall.

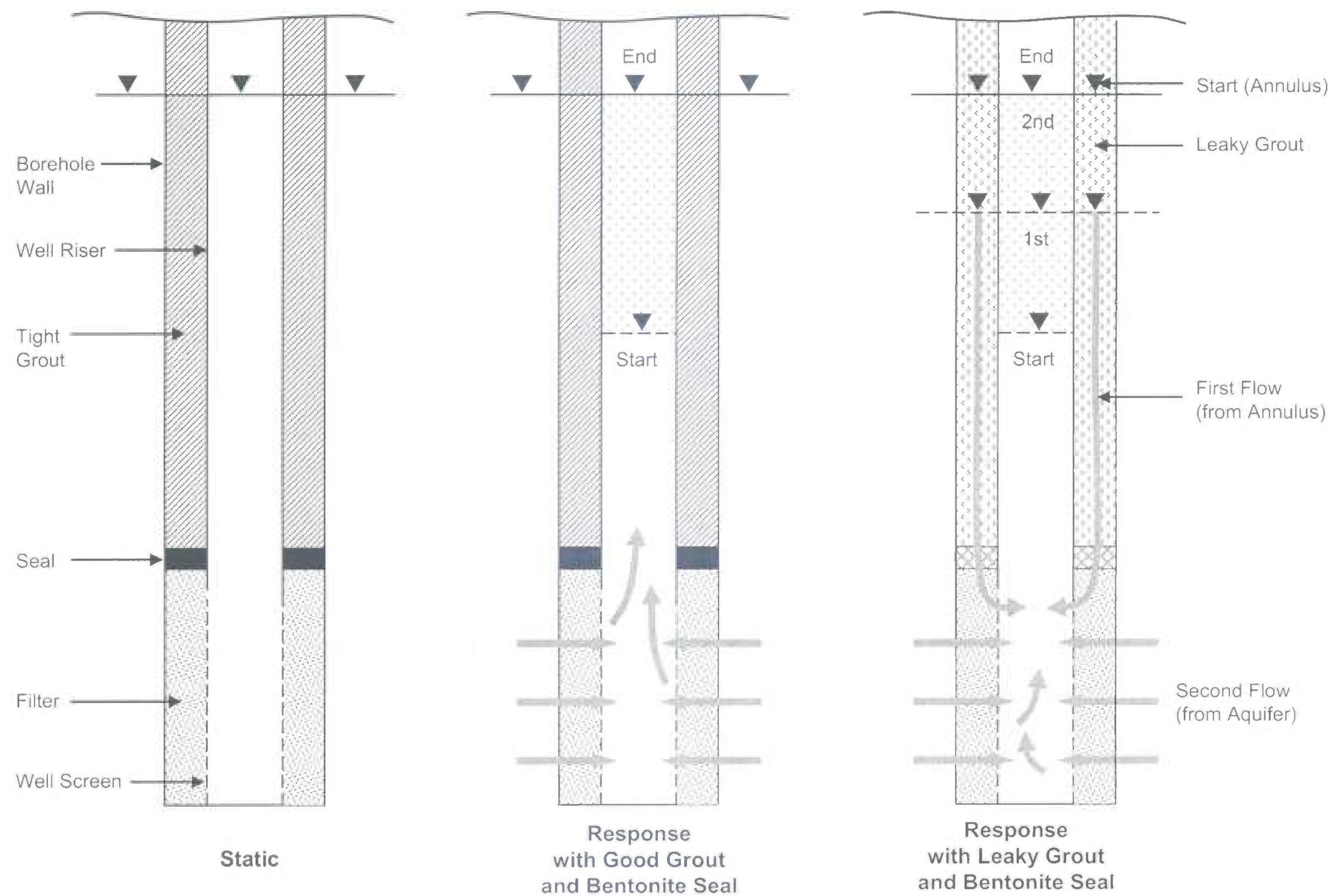

Figure 3. Slug Test Responses.

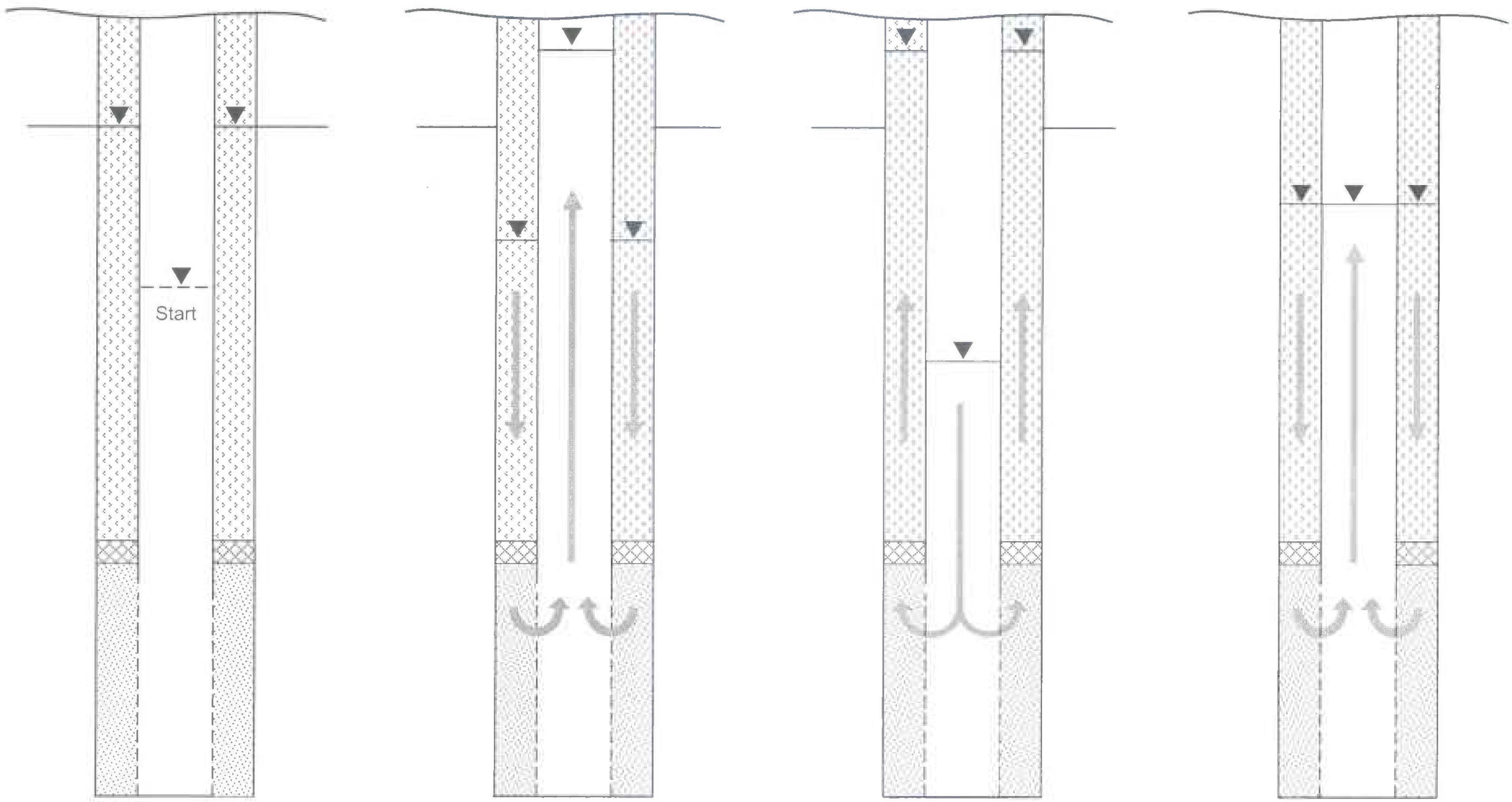

Figure 4. Oscillatory Response in Leaky Well/Borehole Annulus.

Figure 2: MW16-82D Rising Head